Appendix D

Demographic Projections of the Ph.D. Workforce in Biomedical and Behavioral Research, 1995-2005

The growth of any workforce is always subject to unexpected change—to new technologies, new market conditions, and changing national needs. One can, however, make provisional projections if the current workforce can be accurately defined and if acceptable assumptions can be made about the entry of new workers into the field and their propensity to change fields, retire, or die. Using the best available data and what seem to be reasonable assumptions, such projections are made here over the period 1995-2005 for two major groups in the health research workforce: Ph.D.s in the basic biomedical and the behavioral and social sciences. Because of limited data, the projections do not include Ph.D.s in the clinical sciences or health care professionals in any field of health-related research. The assumptions used in projecting the workforce are essentially demographic. That is, they rely on historical tendencies of workers grouped by age and sex to enter, remain in, and leave the biomedical and behavioral workforce. Whether workers will act in accordance with such tendencies will of course be heavily affected by the job market, but the demand for labor is not directly modeled in this exercise.

The Ph.D. workforce in both biomedical and behavioral research has grown steadily over several decades, and projections show they will continue to grow from 1995 to 2005, though at varying rates: 3.4 percent annually in biomedical research and 1.2 percent in behavioral research. Growth in each field is projected to be greater among females than males, so that, by 2005, the number of females in biomedical research will reach about half the number of males, while females in behavioral research will about equal the number of males. The workforce will continue to grow older in each field, an inevitable result of slower workforce growth and longer times to degree, particularly in the behavioral sciences. By 2005 the median age among biomedical scientists is projected to have increased from 45.3 years to 46.2 years, and the median age among behavioral scientists will have risen more substantially from 48.8 years to 52.4 years.

These projections rely on a variety of assumptions: trends in the numbers of Ph.D. graduates extrapolated from previous trends, retirement schedules and rates for moving in and out of employment, and continued substantial shifts between science and nonscience jobs, especially among relatively younger Ph.D.s. Reasonable alternative assumptions about trends in graduates and immigrant Ph.D.s do not alter the projections substantially.

Simulations were run to determine the number of graduates required to maintain a constant workforce. In each field the required graduates would be substantially below current numbers. If, instead, the workforce were constrained to grow in parallel with the U.S. workforce as a whole, the number of graduates in behavioral and social research would decline initially and then recover. In basic biomedical fields, on the other hand, the number of graduates would be substantially smaller than current numbers.

BACKGROUND AND ASSUMPTIONS

The Potential Workforce

By definition, the basic biomedical sciences include biological science fields from anatomy to zoology (excluding the plant sciences), as well as the related fields of veterinary medicine, biomedical engineering, and pharmaceutical chemistry. Other life sciences are generally excluded but may be included in tabulations of graduate students because of differences in the design of the national surveys of graduate students and Ph.D.s. The behavioral and social sciences of interest include psychology, sociology, anthropology, demography, and speech-language pathology and audiology. Because this study focuses on research scientists, clinical, counseling, and school psychologists, who constitute more than 40 percent of recent Ph.D. graduates in these disciplines combined, are excluded in most tabulations.

The potential research workforce in the targeted fields is defined to include Ph.D.s who are either (1) employed full- or part-time in science or engineering, (2) unemployed but seeking work, or (3) not employed and not seeking work but not retired. Employment includes postdoctoral appointments. Because of data limitations, biomedical and behavioral Ph.D.s are included even if they are working in other scientific or engineering fields. Similar data limitations also result in the exclusion of Ph.D.s with degrees in other fields who have chosen to work in biomedical or behavioral sciences.

Those not employed and not seeking work are usually considered not to be in the labor force (and will be labeled as such). Among Ph.D.s in these fields, this group is overwhelmingly female. They move in and out of employment, and with the proportion of female Ph.D.s increasing, those not in the labor force are important to track as a potential source of trained labor. (The inclusion of this group is also the reason for using the somewhat unconventional label "potential workforce.")

People are assumed to enter the potential workforce when they (1) graduate with a Ph.D. in the biomedical or behavioral sciences and stay in the U.S., (2) immigrate to the U.S. after earning a Ph.D. abroad in these fields, or (3) shift from a job outside science to a job in science. The third category includes the few shifts from jobs outside science to unemployment or out of the labor force. Some additional possibilities that also involve small numbers of people will be ignored: return from retirement and, for U.S.-trained Ph.D.s. working abroad, return migration. (Excluding a return from retirement is one reason for distinguishing the retired from those not in the labor force, a number of whom return to employment.)

People are assumed to leave the potential workforce if they (1) take employment outside science, (2) retire, or (3) die. They may also emigrate, but data on emigrants are inadequate for analysis.

Figure D-1 illustrates the different groups and potential movements among them. Only the potential workforce itself and its three components—the employed, the unemployed, and those not in the labor force—will be projected, though for this purpose movement into and out of other groups has to be tracked.

Data

Survey data provide a picture of the potential workforce and show how it has evolved and thus permit parameters to be selected for the above model based on recent history. One source is the Survey of Doctorate Recipients, a longitudinal biennial survey dating

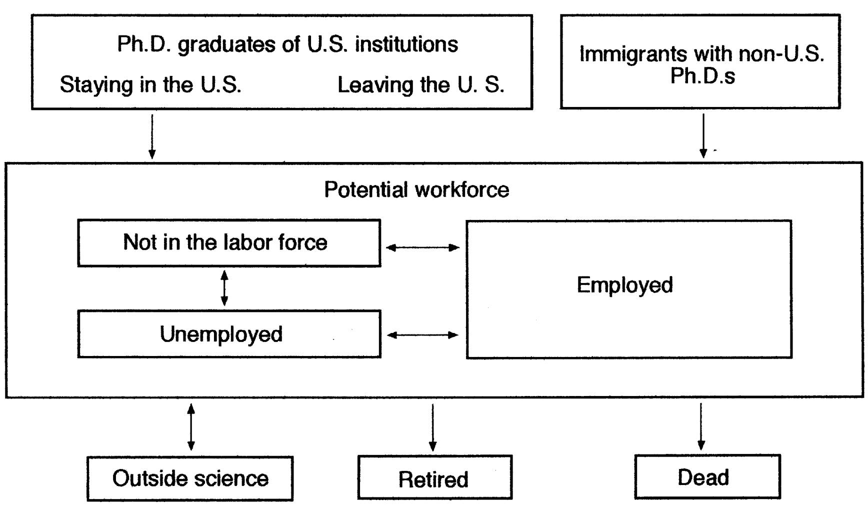

FIGURE D-1 The potential Ph.D. workforce of biomedical and behavioral scientists.

back to 1973. From 1973 to 1989, the universe for this survey included all Ph.D.s with degrees earned in the U.S. who planned to stay in the country, plus Ph.D.s with degrees from abroad who were employed in the U.S. prior to 1973 and received their doctorates no more than 42 years prior to the survey year. In 1991 the latter group was dropped, and an age limitation of 75 years was imposed.[1]

Ph.D. graduates entering the workforce are reported by the Survey of Earned Doctorates, a census conducted annually since 1920, with all results kept in a virtually complete database of research doctorates called the Doctorate Records File. Annual reports on the survey have been issued since 1967.[2]

Graduate enrollees and current enrollment were obtained from the Survey of Graduate Students and Postdoctorates in Science and Engineering.[3] This survey of graduate institutions provides a time series for current enrollment from 1979. Some data are available before 1979 but are irregular; in some years they are missing altogether and in others they fail to distinguish males from females. The survey also began to report numbers of first-time, full-time enrollees by field in 1980 but did not distinguish between clinical and nonclinical graduate students in psychology until 1988.

[1] National Science Foundation. *Characteristics of Doctoral Scientists and Engineers in the U.S.: 1991*. Arlington, Va.: NSF, 1994.

[2] National Research Council. *Summary Report 1996: Doctorate Recipients from U.S. Universities*. Washington, D.C.: National Academy Press, 1998.

[3] National Science Foundation. *Graduate Students and Postdoctorates in Science and Engineering: Fall 1997*. Arlington, Va.: NSF, 1999.

Immigration information was obtained from the 1993 and 1995 Surveys of College Graduates, which followed up a sample of postsecondary degree holders from the 1990 U.S. census.[4] These surveys, as well as the Survey of Doctorate Recipients, use a weighted sample. Weighted numbers that represent the population will be reported throughout; these numbers do not represent actual respondents. Respondents are often fewer, especially for immigrants, and particular figures cited may not have much precision. Where possible, data are aggregated to minimize this problem.

Data were also obtained on mortality from TIAA/CREF, the primary pension system for individuals employed in education and research.

Some analysis and interpretation of these data will be necessary, but this is not the main purpose of this exercise. For more information on the characteristics of and past trends in the workforce, a variety of other studies are available, such as *Trends in the Early Careers of Life Scientists*.[5]

The Current Workforce

The current potential workforce, which serves as the base for the projection, consists of 83,000 biomedical research Ph.D.s and 52,300 behavioral research Ph.D.s, according to the 1995 Survey of Doctorate Recipients (see Table D-1). Not counted in these figures are those

[4] National Science Foundation. *SESTAT: A Tool for Studying Scientists and Engineers in the U.S.* Arlington, Va.: NSF, 1999.

[5] National Research Council. *Trends in the Early Careers of Life Scientists*. Washington, D.C.: National Academy Press, 1998.

TABLE D-1 Ph.D. Workforce by Employment Status, Plus Those Outside Science and Retired, by Major Field and Gender, 1995

	Biomedical Ph.D.s		Behavioral Ph.D.s	
Employment Status	Male	Female	Male	Female
Employed	57,968	21,009	30,318	20,061
Unemployed	823	414	175	256
Not in labor force	1,097	1,672	466	1,048
Total potential workforce	59,888	23,095	30,959	21,365
Outside science	5,087	2,745	5,147	3,519
Retired	5,535	1,091	3,889	1,024

NOTE: The workforce is defined to exclude those outside of science and retired. Figures also exclude those over age 75.

SOURCE: Datra are from the Survey of Doctorate Recipients.

employed outside science, who are more numerous among behavioral researchers (8,700) than among biomedical researchers (7,800). Also not counted are Ph.D.s who obtained their degrees outside the U.S., a group that will be considered below.

Women make up 28 percent of the workforce in biomedical research and 41 percent in behavioral research. Most of the workforce—91 percent to 98 percent across broad fields and gender—is employed. Of the small proportions unemployed or not in the labor force, more than half in biomedical research and two-thirds in behavioral research are women.

The workforce in biomedical research is younger: 34 percent are 40 years old or younger, as opposed to 19 percent in behavioral research. Only 30 percent in biomedical research are over 50 years old, as opposed to 40 percent in behavioral research (see Figure D-2). Median ages are 46.5 years among male biomedical scientists, 42.4 years among females, 50.2 years among male behavioral scientists, 46.7 years among females. Since it is slightly older, the workforce in behavioral research could see proportionally more retirements and deaths over the next few decades than the workforce in biomedical research. Since men in both fields are somewhat older, retirements and deaths could contribute to a gradually rising proportion of women in each field.

Among those employed, 3.5 percent in the biomedical workforce and 7 percent in the behavioral workforce are employed less than full-time. The majority of part-time employees in both fields—75 percent—are not seeking full-time work, which suggests that most part-time employment is voluntary. Close to half the individuals working part-time in biomedical research and two-thirds of those in behavioral research are women. Part-time employment among women tends to be concentrated among those age 33-50, whereas part-time employment among men is substantially more common beyond age 60 than among younger men. Trends in part-time employment will not be projected but should be kept in mind. The distribution suggests relatively little possibility for increasing the output of biomedical and behavioral scientists by enticing part-time workers to work full-time.

Entry of New Graduates

Ph.D. graduates in 1995 totaled 5,100 in biomedical research and 2,400 in behavioral research, the equiva-

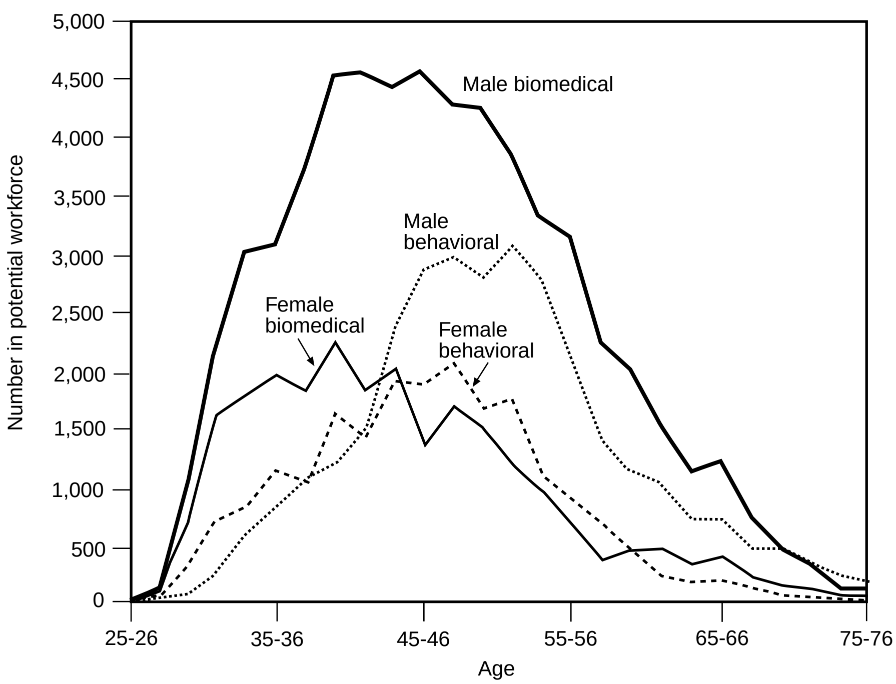

FIGURE D-2 Age distribution of potential workforce in 1995 by field and gender (in two-year age groups). SOURCE: Data are from the Survey of Doctorate Recipients.

lent of 6 percent and 4.5 percent of the potential workforce in the respective fields (though not all of the graduates may have entered the workforce).

The number of Ph.D. recipients in a given year may be expected to depend on the number of students who enrolled in graduate school six to nine years earlier, the time it usually takes to complete the requirements for a Ph.D. The ratio of entering graduate students to Ph.D. recipients six years later, however, is not stable but varies by field and gender as well as over time. This ratio has been as low as 1.4 enrollees per graduate (e.g., for 1990 male biomedical research enrollees) and as high of 2.8 enrollees per graduate (e.g., for 1990 female behavioral research enrollees). Regression analysis confirmed the lack of consistent linkage. When first-year enrollment rose, the number of graduates six to nine years later decreased at least as often as it increased. Regressions based on the total population of graduate students were no more successful. Only when a short time lag was used could one year's pool of students be used to predict the number of graduates in the next year or two.

The lack of a clear relationship between graduate school enrollment and Ph.D. production may be due partly to data limitations and the nature of graduate education itself. To begin with, counts of new students entering graduate school include those seeking master's as well as doctoral degrees. Even among those intending to earn a doctoral degree, time to degree is variable, and the six- to nine-year period allows students many opportunities to drop out. These limitations aside, there is a tendency for the numbers of Ph.D. recipients to rise a year or two after enrollment rises, which suggests that short-term job market conditions may lead to almost simultaneous increases in new enrollees, graduate students, and graduates. In a large pool of students, such economic factors may strongly influence some to finally earn or postpone earning their Ph.D.s in a given period.

The number of graduates therefore can be projected from reported enrollees or current students only for a year or possibly two. An alternative method projects graduates directly on the basis of historical trends (observable for a longer period), recognizing that such curve fitting is at least partly arbitrary. These trends can be quickly summarized. Since the 1960s, graduates have increased in both fields (see Figure D-3). After the early 1970s, however, male graduates in biomedical research remained largely constant for almost two decades before increasing recently, and male graduates in behavioral research declined. Female graduates in both fields have continued to increase.

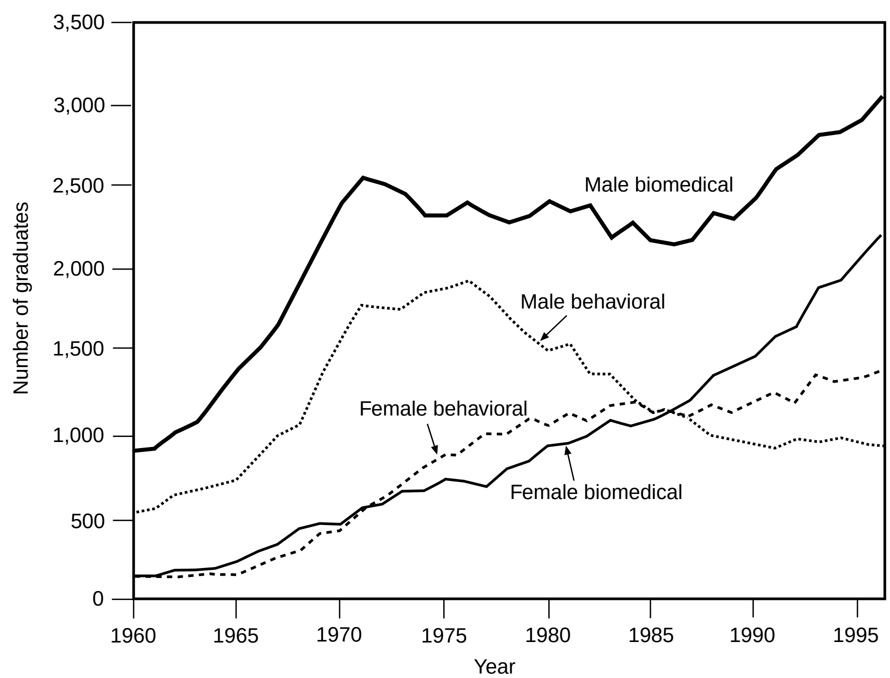

FIGURE D-3 New Ph.D. graduates by field and gender, 1960-96. SOURCE: Data are from the Survey of Earned Doctorates.

Projections based on these past trends vary depending on the period from which one extrapolates. Alternative periods were chosen—1970-96, 1975-96, and 1985-96—and trends were quantified using regression analysis. The regressions were for new graduates by field and gender, predicted from calendar year and year squared. These regressions generally fit the data well, with all R^2s being above 0.80. The regressions for 1985-96 typically showed the fastest rates of increase. None of the regressions for biomedical research indicated future declines in graduates, but for behavioral research the regressions for 1970-96 did suggest future declines (see the Technical Note later in this appendix).

For current purposes, the regressions for 1985-96 can be taken to define one possible set of scenarios for future graduates. The number of graduates increases in each group every year, in these scenarios, by 2 percent to 6 percent, faster than in trends extrapolated from other regressions. These may, therefore, be considered "high-growth" scenarios. An alternative "low-growth" scenario, for behavioral research graduates, may be the declining-graduates regressions based on 1970-96 data. For biomedical research graduates, simply keeping the numbers constant at average levels for 1990-96 will be used to produce a low scenario. In each case, a "medium-growth" scenario will be simply the average of the high and the low scenarios.

Some proportion of graduates, particularly non-U.S. citizens with temporary visas, will not stay in the country after graduation. The first issue is the number of graduates on temporary visas. By 1996, noncitizens had risen to 37 percent of biomedical research graduates and 16 percent of behavioral research graduates. About two-thirds of these were on temporary visas. The proportion of graduates on temporary visas almost doubled from 1985 to 1990, but from then on it fluctuated with no apparent pattern, while the proportion on permanent visas was increasing rapidly (see Figure D-4). The Chinese Student Protection Act of 1992 (which provided Chinese students with protection from political turmoil at home by allowing them to apply for permanent U.S. residency) had some influence on trends during the 1990s.[6] As a result of the law, the percentage of students from China who were permanent U.S. residents at the time they received their degree increased from 5

[6] National Research Council. *Summary Report 1995: Doctorate Recipients from U.S. Universities*. Washington, D.C.: National Academy Press, 1996.

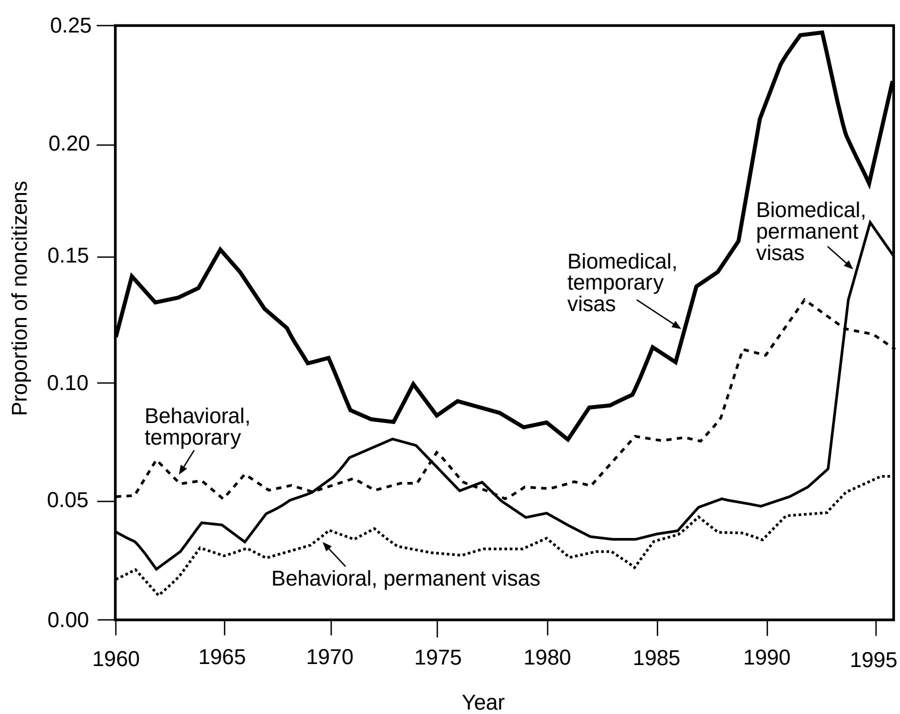

FIGURE D-4 Proportion of noncitizens among U.S. Ph.D. graduates by field and visa type, 1960-96. SOURCE: Data are from the Survey of Earned Doctorates percent in 1990 to 80 percent in 1995. Extrapolating from these trends would, therefore, be unwise. Instead, for projection purposes, the proportion of temporary visas will be assumed to stay at its 1990-96 average for each group defined by field and sex. This means that those on temporary visas will be projected at 24 percent among male biomedical research graduates, 18 percent among females, 16 percent among male behavioral research graduates, and 9 percent among females.

The proportion of those on temporary visas that stay in the U.S. also appears to be rising, but these data are more difficult to obtain. By identifying Ph.D. graduates who later show up in Social Security Administration data, Finn[7] estimated that 60 percent of 1993 noncitizen graduates in the life sciences were still in the U.S. in 1995. The life sciences are somewhat broader than the biomedical sciences, for they also include agricultural sciences and basic biological sciences. A parallel estimate for 1993 graduates in the social sciences more broadly defined (including, besides those listed above, economics and urban and regional planning) was 35 percent. These proportions could be rising, given that equivalent estimates for the 1990-91 cohort in each field were 40 percent and 28 percent, respectively. As cohorts age, the numbers of foreign graduates still in the U.S. do not appear to fall—over five years or so, they may actually rise as Ph.D.s return from abroad. In the absence of more definitive evidence, however, the estimates for the 1993 cohort will be adopted here for both males and females for the projection period. All other graduates, citizens as well as noncitizens on permanent visas, will be projected to stay in the U.S.

Ph.D. graduates in these fields are most often in the age range of 30-34 years but may be as young as 25 years or over 45 years. The proportion age 25-29 years rose sharply from the 1960s to the 1970s and then declined while the proportion older than 29 years was rising. Greater delays in obtaining bachelor's degrees, delays in enrollment in graduate school, and increases in the time required to earn a Ph.D. may all contribute to this trend. Figure D-5 shows how graduates are dis-

[7] Finn, Michael G. "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 1995." Oak Ridge, Tenn.: Oak Ridge Institute for Science and Education, 1997.

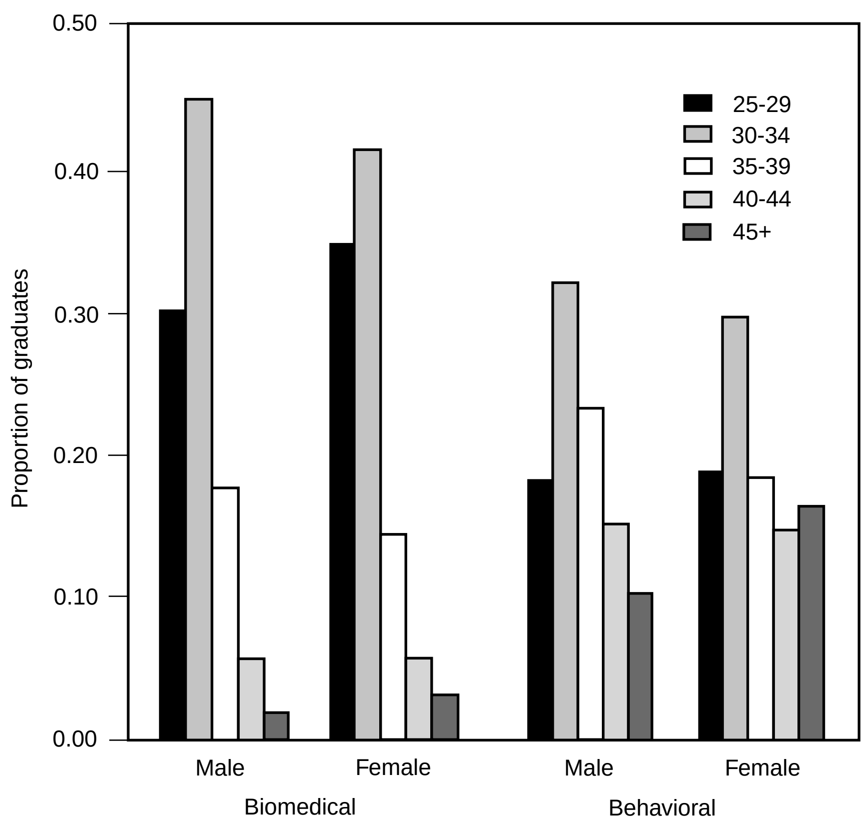

FIGURE D-5 Proportion of Ph.D. graduates in each age group by field and gender: 1990-96 averages. SOURCE: Data are from the Survey of Earned Doctorates.

tributed by age, using averages for the period 1990-96. The proportion of older graduates in behavioral research has reached quite a high level. Among female behavioral scientists particularly, graduates age 40 years and over make up almost a third of the total. These five-year age distributions will be used in the projections, converted to smoothed single-year distributions.

How soon these new graduates become employed is not known. Throughout the projections they are assumed to distribute across possible employment status immediately and in the same proportion as other graduates of their age already in the workforce or employed outside science in the year of their graduation.[8]

Entry Through Immigration

Ph.D.s who obtain their degrees abroad and then immigrate into the U.S. are not included in these data. Unlike foreign students who obtain Ph.D.s in the U.S., immigrants with Ph.D.s obtained abroad are not in such compendia as the Doctorate Records File. Their estimated numbers are reported in Table D-2 from the 1995 Survey of College Graduates, which followed up those identified in the 1990 census. Immigrant Ph.D.s do make a contribution to the workforce, particularly in biomedical research, where they make up about a tenth of the number of U.S. Ph.D.s. Their numbers, broken down by age and employment status, will therefore be added to the base population.

These data on the stock of Ph.D. immigrants cannot be used to determine their flow, because this survey does not have dates of entry into the U.S. Instead the 1993 Survey of College Graduates will be used. Both surveys relied on the 1990 census as a frame and covered the same universe. The 1993 survey, which is closer to the date of entry for the immigrants, is therefore preferable.

The immigrants in 1993 were broken down by age, field, and gender, as well as date of entry into the U.S., and are coded in the survey file as before 1981, 1981-82, 1983-84, 1985-86, or 1987-90. The size of each cohort when it entered the country (at the midpoint of period of entry) was estimated using assumed mortality and retirement rates described below. (See the Technical Note later in this appendix for an explanation of the process of reverse survival. The cohort entering before 1981 was excluded because of the indefinite dates of entry.) Inferring the original number of entrants this way has little effect on the number of younger immigrant Ph.D.s but can substantially increase the number of older ones beyond the numbers reported in cross-sectional surveys.

Given the small number of immigrants in the survey, estimated annual numbers by period are irregular, including implausible zero totals for some groups in some periods. A strong upward trend in total immigrants across all ages does appear over time in biomedical research, and an upward trend may also be possible in behavioral research (see Figure D-6). Depending on how growth is estimated and for which groups, the annual growth rate for immigrant Ph.D.s over the period 1981-90 is around 10 percent to14 percent, a trend that might be compared to the recently

[8] In these calculations the 1995 graduates are assumed to enter the workforce and be counted in the figures for 1995 described previously. Graduates in 1996, for whom data are also available, are added to the workforce in 1996, and the scenarios based on regressions described above are used to give total graduates in subsequent years.

TABLE D-2 Immigrant Ph.D.s by Employment Status, Field, and Gender, 1995

	Biomedical Ph.D.s		Behavioral Ph.D.s	
Employment Status	Males	Females	Males	Females
Employed	5,471	2,147	355	407
Unemployed	135	176	0	0
Not in labor force	120	406	0	89
Total potential workforce	5,726	2,729	355	496
Outside science	1,413	605	1,330	380
Retired	471	71	0	60

SOURCE: Data are from the Survey of College Graduates.

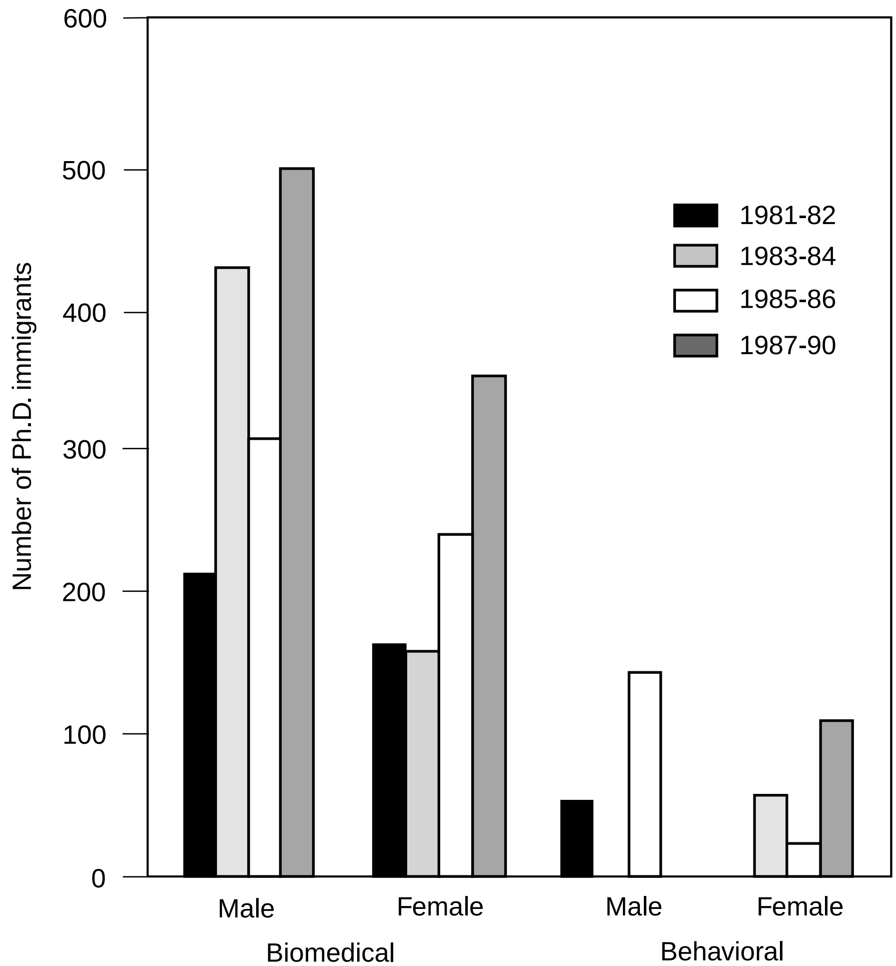

FIGURE D-6 Estimated annual Ph.D. immigrants by period, field, and gender. SOURCE: Data are from the Survey of College Graduates.

increased proportion of U.S. Ph.D.s awarded to foreign nationals.

Averaging across periods suggests that 600 biomedical scientists and 100 behavioral scientists immigrate annually. In biomedical research, about two-thirds of these are under 35 years of age when they immigrate, in contrast to behavioral research, where only a third are under 35.

To project immigrant flow, annual numbers by age were averaged across periods, again leaving out the period before 1981, and age patterns were smoothed using five-year moving averages. These numbers will be held constant and paired with the "medium-growth" projections of graduates in the central projections, which will therefore incorporate the typical migration levels for 1981-90. Alternatively, immigrants may be excluded altogether; this option will be paired with the "low-growth" projections of graduates. (For the first year at least, eliminating immigrants has about the same effect on total numbers as moving from medium to low graduate projections.) A third option is rising immigration. Immigrant Ph.D.s will be assumed to increase at an annual exponential growth rate of 0.10; this option will be paired with the "high-growth" projections of graduates. All these projections of future migration trends tend to understate the impact of immigration. The medium and high options are based on the average over a decade rather than on the high point reached closer to the start of the projection. More moderate growth is posited in the high option (rather than 14 percent) because of uncertainty about whether such growth would be sustainable. In the high option the annual number of immigrant biomedical scientists already rises from 600 to 1,600.

Other Entries, Exits, and Transitions

Other ways to enter or exit from the potential workforce must be examined to establish projection parameters. To complete the picture, change of status (for example, from employed to unemployed or not in the labor force) will also be examined.

The data to be considered, already used in determining the current workforce, are derived from the biennial Survey of Doctorate Recipients. Ph.D.s were classified by employment status in 1985 and their subsequent status in 1987 was determined. This tabulation was repeated for each succeeding two-year cycle. The data were then pooled across cycles to provide enough cases to support the estimation of age-specific transition rates.

Table D-3 collapses the data further across age groups to reveal the overall picture. For each group defined by major field and gender, the majority of Ph.D.s are employed at the beginning and end of each biennium. The next largest category includes those employed outside science, who make up 5 percent of such cases among biomedical Ph.D.s and 12 percent among behavioral Ph.D.s.

The most important transition results from mobility between employment in science and employment outside science. Almost 5 percent of those employed in science have shifted to jobs outside science two years later, whereas a third of those originally outside science have become employed in science. Those moving out of science, however, still outnumber those moving in, by a ratio of 5:3 overall. The peak ages for moving out of science are 39 to 49 years (see Figures D-7 and D-8).

Examined over time, job shifts into and out of science appear to rise and fall together in each field. The frequency of shifts is also correlated across fields and between males and females, which suggests the importance of market factors—perhaps the availability of university positions or research funds—affecting these fields. Over time the frequency of job shifts shows no apparent overall trend. Shifts appeared to reach a peak in 1991, which may have been due to economic conditions but could also have been the result of survey modifications.

The next most important transition is employment to retirement. In a typical two-year period, less than 3 percent of researchers make this transition (see Table D-3). The proportion retiring is of course strongly patterned by age; it is essentially zero below age 50 and rises quickly from age 60 on (see Figure D-9). Rates for females appear somewhat more volatile, possibly because of a smaller base, and may be slightly lower than for males, though the effect may be somewhat offset by the greater tendency for retired men to return to work. (Those who return to work are few overall and are essentially ignored here.) When examined for 5- and 10-year age groups among those 50 years old and over, retirement rates show no detectable trend over time.

Table D-3 indicates that transitions into and out of unemployment and into and out of not in the labor force involve relatively small numbers (though, like other reversible transitions, these might be understated given the two-year time frame). Moving into and out of the labor force is clearly more important among women in both fields, however. Substantially larger numbers of women than men leave the labor force. Under age 50, men outnumber women among the employed by 2-3 to 1. But women outnumber men by similar proportions among those who leave the labor force.

The data on Ph.D.s with U.S. degrees who reside abroad require clarification. Because of changes in survey methodology, changes in the status of these Ph.D.s are not available after 1991. Some Ph.D.s do seem to rejoin the U.S. workforce, but in the absence of data on current numbers abroad, one cannot reliably include this transition in the calculations.

Transition rates from these data were calculated for two-year age groups over two-year periods. Rates were estimated conditionally. For example, the rate for moving from employed to not in the labor force was estimated conditional on nonretirement (i.e., excluding those who retired). To facilitate projections, rates were converted to annual rates (using the square root of the survival rate) and smoothed using five-year moving averages. Smoothing was not applied to retirement rates; the peaks at ages 65 and 70, which already appear less sharp because of the biennial data, could reflect actual behavior.

Exit Through Death

Mortality rates cannot be estimated reliably from these surveys. Instead, life tables were used for TIAA/CREF "participants," mainly university employees and employees of nonprofit organizations. These tables indicate a life expectancy at birth of 74.1 years for males and 79.4 for females. For males the figure is slightly higher than estimates for the general population: 72.5,

TABLE D-3 Initial Employment Status and Status Two Years Later, Pooled 1985-95 Data (percent)

Final Employment Status	Initial Employment Status						
	Employed	Unemployed	Not in Labor Force	Outside Science	Retired	Abroad[a]	Total
			Male biomedical Ph.D.s				
Employed	80.7	0.4	0.2	1.6	0.3	0.3	83.4
Unemployed	0.5	0.1	0.0	0.1	0.0	0.0	0.8
Not in labor force	0.3	0.2	0.4	0.1	0.1	0.0	1.0
Outside science	2.7	0.1	0.0	2.1	0.1	0.0	5.1
Retired	1.8	1.2	0.1	0.1	4.7	0.0	7.8
Abroad	0.2	0.0	0.0	0.0	0.0	1.6	1.8
Total	86.3	2.1	0.7	4.0	5.1	1.9	100.0
Weighted cases[b]	(215,176)	(5,238)	(1,762)	(9,865)	(12,776)	(4,657)	(249,474)
			Female biomedical Ph.D.s				
Employed	74.6	0.9	0.9	2.1	0.1	0.3	78.9
Unemployed	1.0	0.2	0.2	0.1	0.0	0.0	1.6
Not in labor force	1.7	0.3	2.2	0.1	0.2	0.0	4.6
Outside science	3.7	0.3	0.2	3.5	0.0	0.0	7.7
Retired	0.8	0.9	0.1	0.2	3.9	0.0	5.9
Abroad	0.2	0.0	0.0	0.0	0.0	1.1	1.3
Total	82.0	2.7	3.8	6.0	4.2	1.4	100.0
Weighted cases[b]	(58,676)	(1,901)	(2,701)	(4,277)	(2,972)	(1,017)	(71,544)
			Male behavioral Ph.D.s				
Employed	71.4	0.2	0.2	3.2	0.4	0.2	75.6
Unemployed	0.4	0.3	0.1	0.1	0.0	0.0	0.9
Not in labor force	0.2	0.0	0.1	0.0	0.1	0.0	0.5
Outside science	4.9	0.1	0.1	6.7	0.2	0.0	11.9
Retired	2.4	0.0	0.1	0.4	4.2	0.0	7.1
Abroad	0.3	0.0	0.0	0.0	0.8	2.8	4.0
Total	79.6	0.6	0.7	10.5	5.6	3.0	100.0
Weighted cases[b]	(101,843)	(771)	(856)	(13,436)	(7,182)	(3,871)	(127,959)
			Female behavioral Ph.D.s				
Employed	69.8	1.0	0.7	3.0	0.1	0.3	74.9
Unemployed	1.1	0.5	0.2	0.1	0.0	0.1	2.0
Not in labor force	1.1	0.2	1.3	0.4	0.1	0.0	3.0
Outside science	5.8	0.3	0.4	7.7	0.0	0.0	14.3
Retired	1.0	0.0	0.2	0.1	2.5	0.0	3.9
Abroad	0.3	0.0	0.0	0.0	0.0	1.6	2.0
Total	79.1	2.0	2.8	11.4	2.7	2.0	100.0
Weighted cases[b]	(44,007)	(1,126)	(1,540)	(6,348)	(1,518)	(1,129)	(55,668)

[a] Data on those abroad were not collected in 1993 and 1995. This category therefore reflects 1985-91 data only and is almost certainly underestimated.

[b] As explained in the text, the number of cases is weighted to reflect the total population—for this table the combined population for five periods.

SOURCE: Data are estimated from the Survey of Doctorate Recipients.

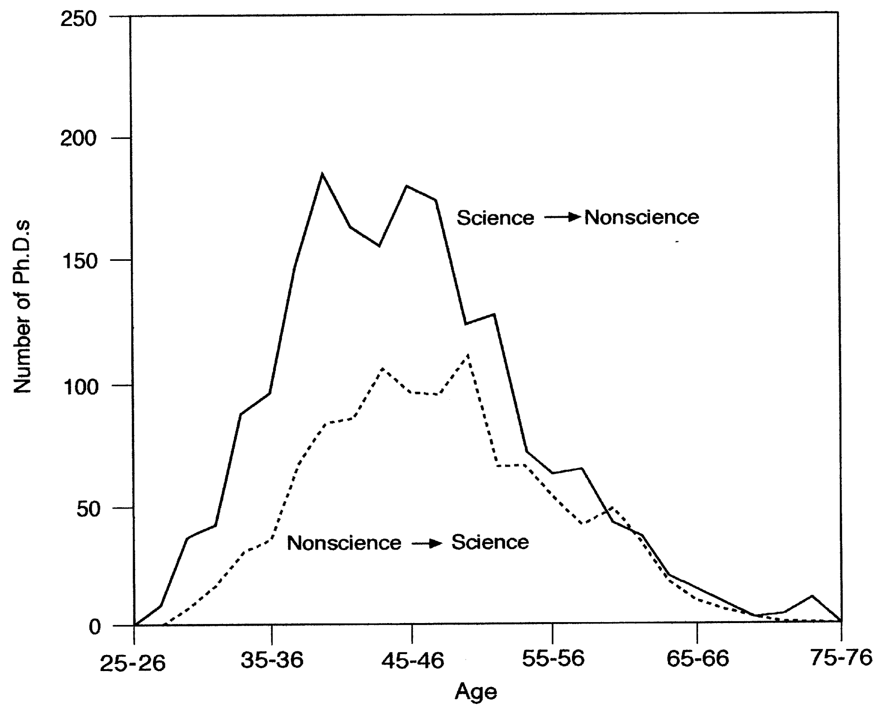

FIGURE D-7 Biennial shifts between science and nonscience jobs by age group: biomedical scientists, 1985-95 averages. SOURCE: Data are from the Survey of Doctorate Recipients.

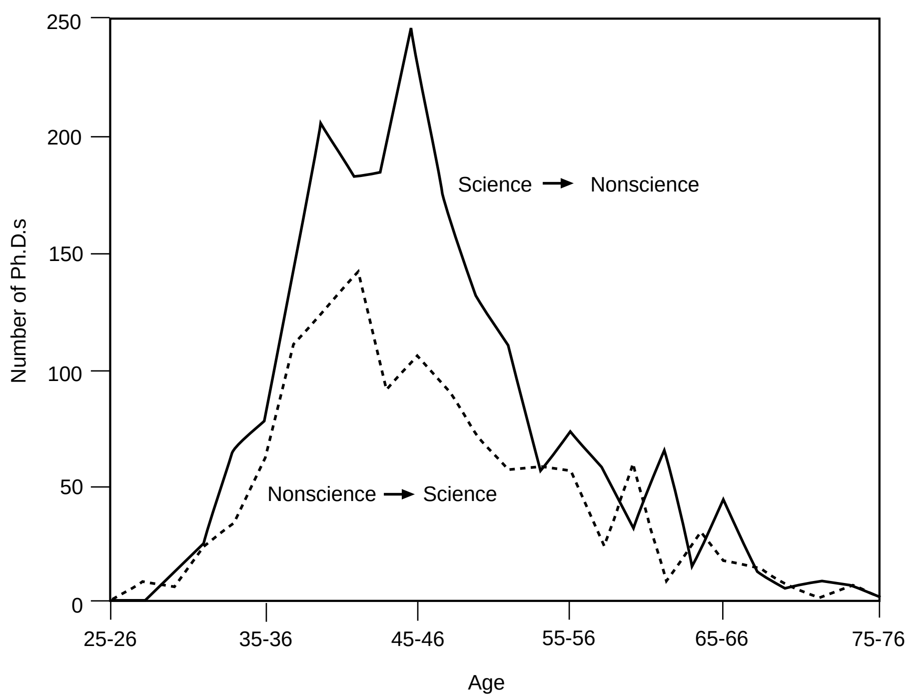

FIGURE D-8 Biennial shifts between science and nonscience jobs by age group: behavioral scientists, 1985-95 averages. SOURCE: Data are from the Survey of Doctorate Recipients.

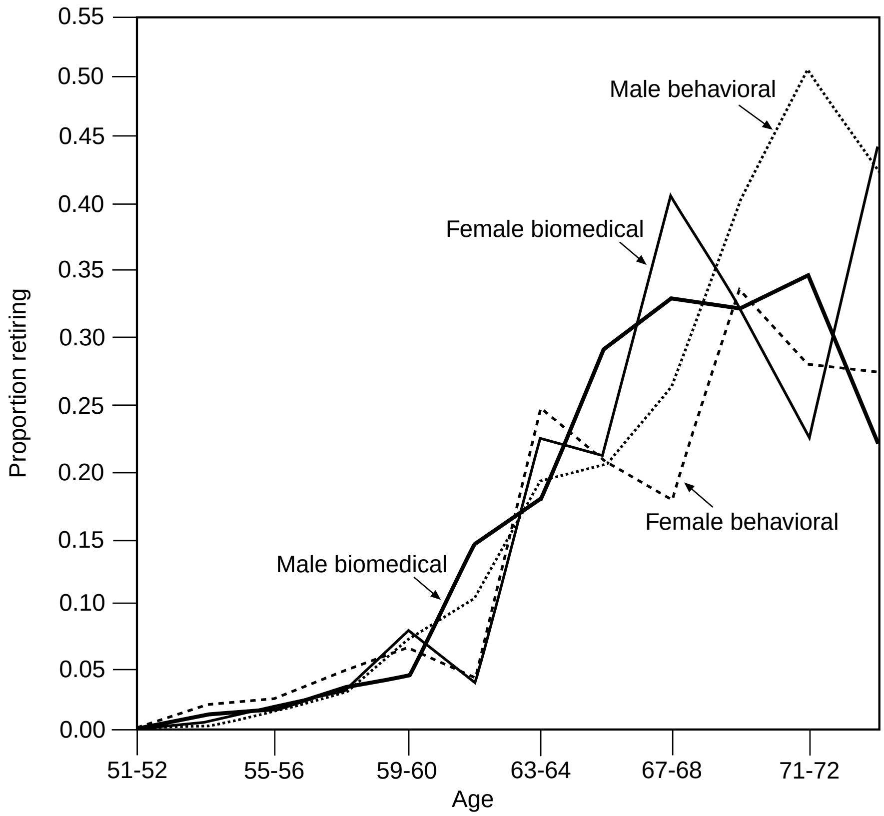

FIGURE D-9 Proportion retiring in two years among those employed in science by age, field, and gender: 1985-95 averages. SOURCE: Data are from the Survey of Doctorate Recipients.

according to the U.S. Census Bureau,[9] and 73.4, according to the U.N. Population Division.[10] One might well expect some such advantage in a more educated group. For females, however, the life expectancy estimate essentially matches estimates for the general population (79.3 and 80.1, according to the same two sources). Since data are not available by field or employment status, the same mortality rates are used for all groups.

PROJECTION RESULTS

Projection of the Workforce

Using the assumptions just outlined, 10-year workforce projections were constructed for each of four groups defined by field and gender. An initial overview of the results follows; details of the procedure are provided in the Technical Note later in this appendix.

Figure D-10 shows the workforce in biomedical and behavioral research over time. Data from 1985 to 1995 are derived from surveys, and data from 1995 on are projection results. Three alternative projections are shown, assuming high, medium, and low numbers of Ph.D. graduates (and corresponding high, medium, and low numbers of immigrant Ph.D.s as described above). The high and low projections are meant to set possible bounds on future trends rather than to reflect likely alternatives.

The workforce in biomedical research, which is 70 percent larger than that in behavioral research, is projected to grow more than three times as fast. The annual growth rate of the biomedical workforce over the period 1995-2005 is estimated at 3.4 percent in the medium projection and in the high and low projections at 4.4 and 2.2 percent. The workforce in behavioral research, on the other hand, will also grow (at 1.2 percent in the medium projection). In the high projection, an-

9 U.S. Bureau of the Census. *Population Projections of the U.S. by Sex, Race, and Hispanic Origin: 1995 to 2050*. Washington, D.C.: U.S. Bureau of the Census, 1996.

10 United Nations. *World Population Prospects 1950-2050: The 1998 Revision*. New York: UN, 1999.

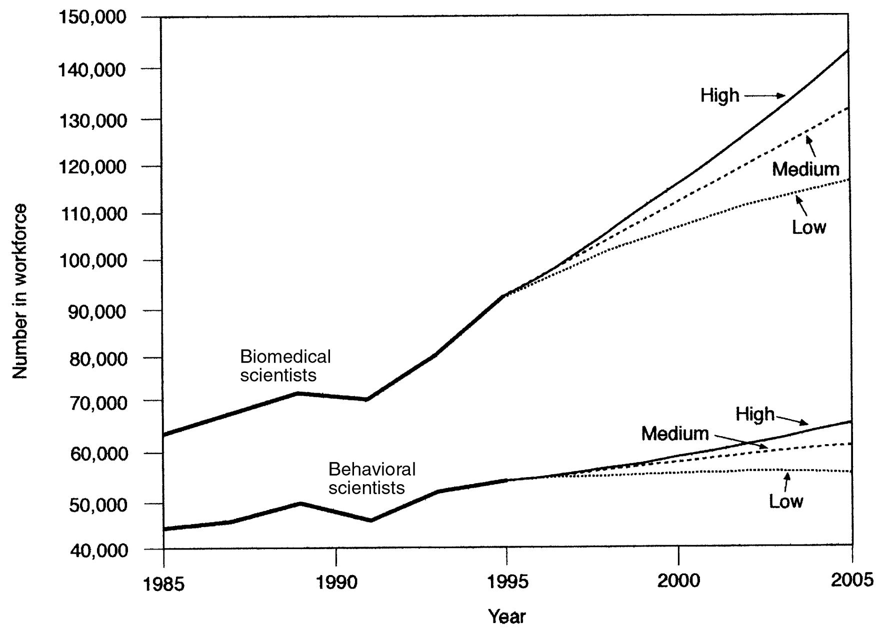

FIGURE D-10 Workforce projections with varying numbers of graduates: biomedical and behavioral scientists, 1985-2005.
SOURCE: Data are from projections described in the text.

nual growth rises to 2.0 percent, but in the low projection annual growth over the entire period is barely positive at 0.3 percent, which reflects an initial slight increase to the year 2003 and a subsequent modest decline.

The medium annual growth rate in biomedical research is higher than that projected by the U.S. Bureau of Labor Statistics[11] for 1996-2006, which is 2.1 percent in the life sciences. For behavioral research, on the other hand, the medium rate is close to that estimated by the bureau, which is 0.9 percent in the social sciences. (The contrasts will be discussed further in the concluding section below.)

The projected growth for both fields may be understood as an extension of growth in the previous decade. In 1985-95 the biomedical research workforce (excluding immigrant Ph.D.s) grew 3.0 percent annually and the behavioral research workforce grew 1.2 percent annually. Projections, however, do not reproduce the variability in past trends. The apparent fluctuations in growth between 1985 and 1995—large increases at some points and occasional declines at others—might be due to the complex weighting procedures, which vary among the surveys or to survey errors or sample variability. These data probably deserve closer examination, but projections nevertheless address the most important trends, around which considerable annual variation is possible.

Two qualifications are useful regarding Figure D-10 and subsequent figures. First, the 1995 estimates shown are smoothed and adjusted and so differ slightly from the biennial survey reports. Second, immigrants with Ph.D.s are included from 1995 on but not in the earlier survey data, which accounts for some increase.

The actual numbers from the medium projection, which assumes a medium trend in graduates and constant immigration, show differential growth between males and females (see Table D-4). Male biomedical scientists will increase by 17,200 and female biomedical scientists by 19,900 over the decade. In spite of its smaller base, the female workforce has an annual growth rate two and a half times as high as the male (5.7 percent versus 2.3 percent). In behavioral research the contrast is even sharper, since males are projected to decrease (by 1,300 over the decade) and females to increase (by 8,000).

Figures D-11 and D-12 show the composition of the workforce in each field in the medium projection, with males and females disaggregated among the employed, though not among the much smaller numbers of persons unemployed, not in the labor force, and outside science. The graphs illustrate the consistency with ear-

[11] U.S. Bureau of Labor Statistics, Office of Employment Projections. "National Industry-Occupation Employment Projections 1996-2006." Washington, D.C.: U.S. Department of Labor, 1997.

TABLE D-4 Projected Ph.D. Workforce and Ph.D.s Outside Science, Assuming Medium Trend in Graduates and Constant Immigration, 1995-2005

	Biomedical Scientists				Behavioral Scientists			
	Male		Female		Male		Female	
Year	Workforce	Outside Science	Workforce	Outside Science	Workforce	Outside Science	Workforce	Outside Science
1995	65,615	6,500	25,825	3,350	31,315	6,477	21,862	3,900
1996	67,668	5,931	27,775	3,360	31,204	6,285	22,628	4,189
1997	69,620	5,544	29,657	3,401	31,153	6,134	23,404	4,458
1998	71,480	5,308	31,570	3,487	31,107	5,996	24,199	4,702
1999	73,260	5,188	33,510	3,607	31,037	5,865	25,008	4,925
2000	74,959	5,154	35,470	3,751	30,931	5,742	25,824	5,125
2001	76,604	5,176	37,455	3,912	30,809	5,628	26,633	5,304
2002	78,211	5,232	39,480	4,084	30,678	5,520	27,447	5,467
2003	79,781	5,315	41,532	4,269	30,517	5,419	28,263	5,628
2004	81,309	5,415	43,609	4,465	30,298	5,306	29,062	5,788
2005	82,792	5,525	45,719	4,674	30,043	5,192	29,838	5,943

SOURCE: Data are from projections described in the text.

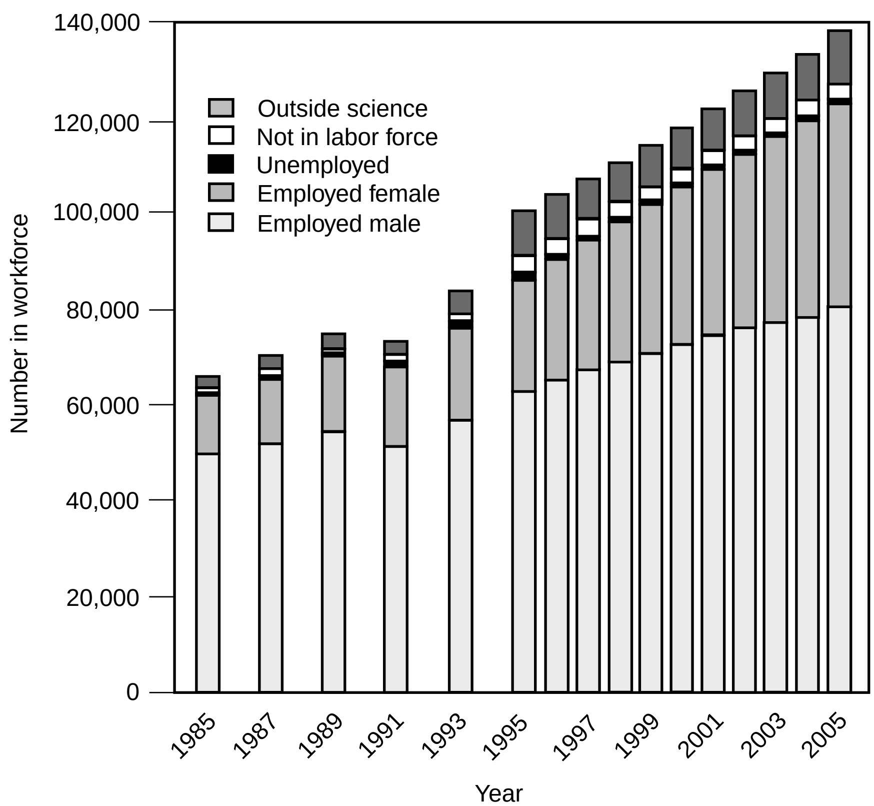

FIGURE D-11 Reported and projected workforce by employment status and Ph.D.s outside science: biomedical scientists, 1985-2005. SOURCE: Data are from the Survey of Doctorate Recipients and projections described in the text.

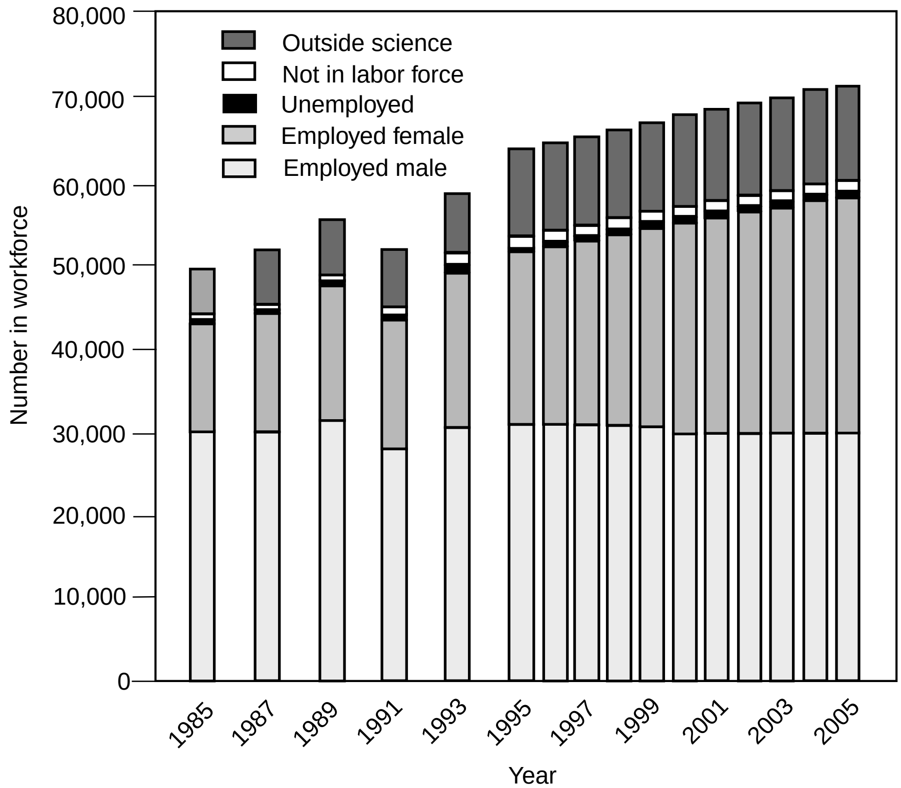

FIGURE D-12 Reported and projected workforce by employment status and Ph.D.s outside science: behavioral scientists, 1985-2005. SOURCE: Data are from the Survey of Doctorate Recipients and projections described in the text.

lier trends of projected trends in the workforce. They also underline the contrast between biomedical research, where each component of the workforce is growing vigorously, and behavioral research, where employed males—the largest component—are declining in numbers.

Of the smaller components of the potential workforce, the unemployed are so few in number as to be barely visible in these figures. At 1.7 percent of the potential biomedical research workforce in 1995, their proportion was elevated over earlier levels, and the level after 10 years is projected to settle around 0.7 percent. Among behavioral researchers, on the other hand, the 1995 unemployment level of 0.8 percent is sharply lower than in previous years, and the level at which it settles after a decade is 1.4 percent.

Those not in the labor force, on the other hand, are at least twice as numerous as the unemployed. Their numbers rose sharply in the mid-1990s and are projected to stabilize. In 1995 those not in the labor force composed 3.6 percent of the potential workforce among biomedical Ph.D.s. By 2005 they will make up 2.6 percent of the total, though they will still be more numerous than in 1995. Their projected decline as a proportion of the workforce will signal a return to pre-1993 levels; the simultaneous increase in numbers is possible mainly because of the changing gender composition of the workforce, since 8 percent of women but only 2 percent of men are not in the labor force. Among behavioral researchers, the percentage not in the labor force starts at 3.0 in 1995 but also reaches 2.6 by 2005. The contrast between men and women is similar.

The final group in Figures D-11 and D-12 shows those employed outside science, who are not considered part of the research workforce. As with those not in the labor force, their numbers increased sharply in the mid-1990s. They are projected to continue to increase, though only slowly. From the equivalent of 11 percent of the biomedical research workforce in 1995 they will fall to 8 percent by 2005. In behavioral research those outside science were equivalent to 20 percent of the workforce in 1995 and will be 19 percent of the workforce by 2005.

The median age of the biomedical research workforce, at 45.5 years in 1995, has risen three years since 1985. Over the projection period it will rise less than a year, to 46.2 years by 2005. The rise will be relatively small because more women, who tend to be younger, will be entering the workforce than men. Women will increase from 28 percent to 36 percent of the workforce (see Figure D-13). Their median age was 4 years less than that of men in 1995 and will be 5 years less by 2005.

The behavioral research workforce has been aging more rapidly. The median age rose 5.5 years from 1985, to stand at 48.8 years by 1995. Before the year 2000 it will cross the 50-year mark and by 2005 will stand at 52.4 years. Figure D-14 shows somewhat contrasting patterns for males and females. Males aged 40-59 will be the only broad age group to actually decline in size over the projection, whereas males 60 years old and older will increase 70 percent in a decade. Among females, aging will be reflected mainly in shifts within the broad age group 40 to 59. Females were 41 percent of the potential workforce in 1995 and by 2005 will be half of the total.

These changes in workforce composition result from entries and exits represented in Figure D-15, which show movements not in absolute numbers but as a proportion of the potential workforce by sex. Exits are represented with negative signs. Because the picture does not change greatly across the years of the projection, the year 2000 is used for illustration.

The entrance of graduates is projected to be clearly the most important movement; those actually entering the workforce in 2000 will represent the equivalent of 4 percent of the workforce in each field. Job shifts into and out of science will also be important, with shifts in each direction equivalent to 2 percent of the workforce in biomedical research and 3 percent of the workforce in behavioral research. However, inward and outward job shifts are projected to be almost equal in most cases and to cancel each other out—a change from the excess outward movement in the late 1980s and early 1990s. Annual retirements will account for 1 percent of the

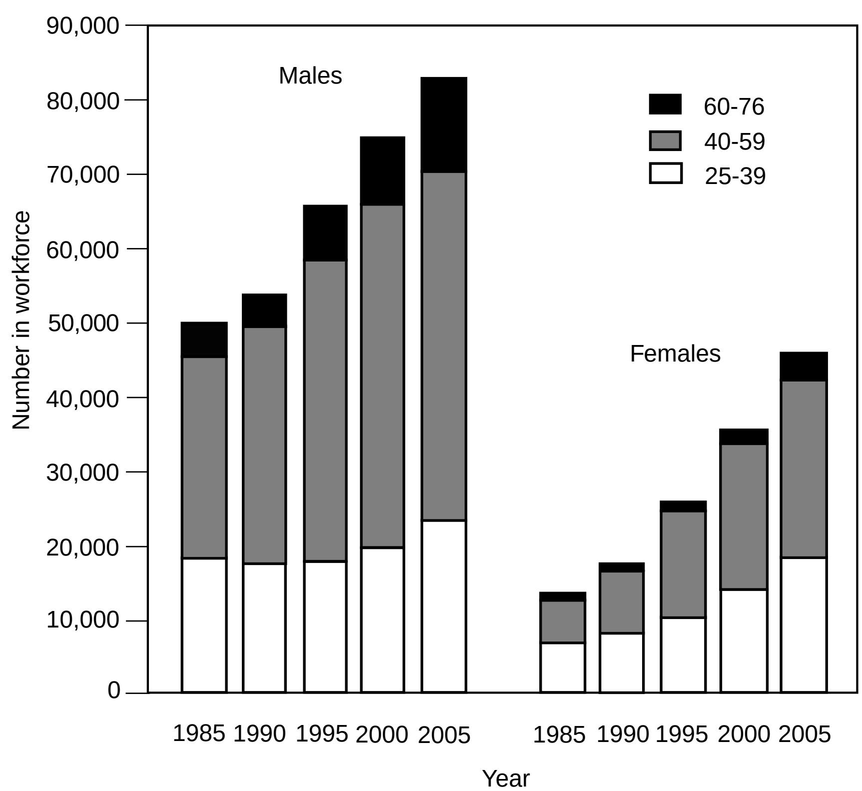

FIGURE D-13 Reported and projected age distribution of workforce: biomedical scientists, 1985-2005. SOURCE: Data are from the Survey of Doctorate Recipients and projections described in the text.

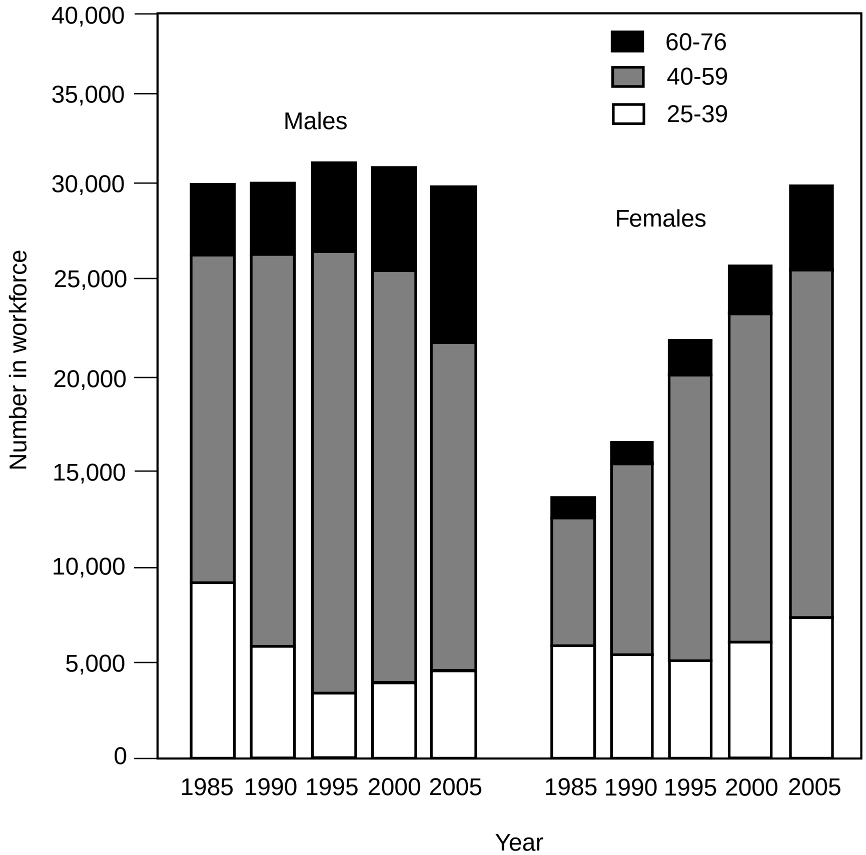

FIGURE D-14 Reported and projected age distribution of workforce: behavioral scientists, 1985-2005. SOURCE: Data are from the Survey of Doctorate Recipients and projections described in the text.

biomedical research workforce and 2 percent of the behavioral research workforce; in each field, annual deaths will be about a quarter of this figure. With graduates projected at more than three times the number of retirements in biomedical research and almost twice the number of retirements in behavioral research, the reasons for expecting continued workforce growth are clear.

The importance of some of these changes varies by gender. New graduates as a proportion of the workforce by sex and field are more likely to be female than male; the proportion of men who retire is twice that of women; and the proportion of deaths is three times greater among men than among women. The ratio of entering graduates to exiting retirees, therefore, varies from more than 8:1 among female biomedical scientists to 1:1 among male behavioral scientists.

If, however, the greater numbers of graduates and rising immigration assumed in the high projection were to occur, the result would be significantly more growth (see Table D-5 and Figure D-10). The potential workforce grows 55 percent in biomedical research in a decade, according to this projection, and 22 percent in behavioral research. The alternative low projection (see Table D-6) shows these workforces growing 25 percent and 3 percent, respectively, over the decade. As a proportion of the workforce, graduates in the high projection are half a percentage point more numerous than in the medium projection (in both fields), and graduates in the low projection are half a percentage point less numerous. Immigrants vary slightly less. Other entries and exits do not vary from their proportions in the medium projection.

Graduates Needed for a Constant Workforce

Instead of asking how the potential workforce will grow, one might ask what hypothetical number of Ph.D. graduates would be needed to keep the workforce constant. This question can be answered by simulating

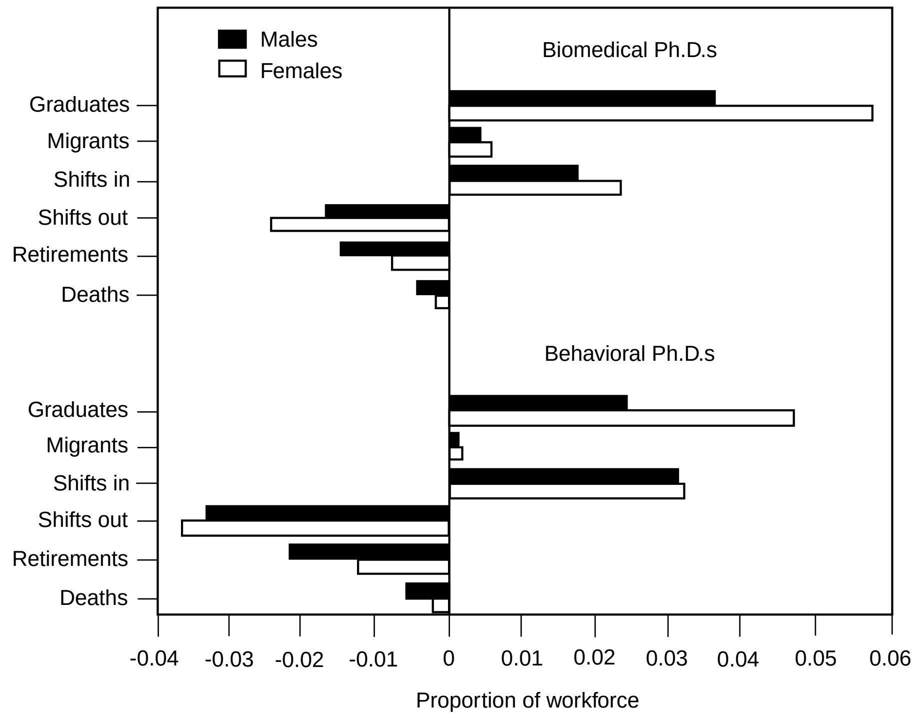

FIGURE D-15 Entries and exits as a proportion of the workforce by field and gender, 2000. SOURCE: Data are from projections described in the text.

workforces staying at their 1995 size for each of the four groups (by field and gender) for a decade (as described in the Technical Note later in this appendix). In these simulations the number of 1996 graduates will be allowed to vary from reported numbers, unlike in the previous projections. The age distribution of graduates will again be held constant and immigration will also be assumed to be constant. Other assumptions, espe-

TABLE D-5 Projected Ph.D. Workforce and Ph.D.s Outside Science, Assuming High Trend in Graduates and Rising Immigration, 1995-2005

	Biomedical Ph.D.s				Behavioral Ph.D.s			
	Male		Female		Male		Female	
Year	Workforce	Outside Science	Workforce	Outside Science	Workforce	Outside Science	Workforce	Outside Science
1995	65,615	6,500	25,825	3,350	31,315	6,477	21,862	3,900
1996	67,704	5,933	27,798	3,362	31,214	6,285	22,638	4,190
1997	69,913	5,556	29,961	3,423	31,275	6,143	23,502	4,466
1998	72,123	5,337	32,252	3,534	31,379	6,016	24,415	4,723
1999	74,350	5,241	34,674	3,685	31,502	5,900	25,382	4,962
2000	76,599	5,240	37,228	3,866	31,635	5,797	26,398	5,184
2001	78,910	5,304	39,924	4,071	31,798	5,710	27,452	5,392
2002	81,300	5,413	42,783	4,300	32,001	5,635	28,559	5,595
2003	83,780	5,558	45,790	4,554	32,227	5,572	29,711	5,803
2004	86,356	5,732	48,957	4,835	32,453	5,504	30,898	6,022
2005	89,032	5,926	52,296	5,144	32,703	5,441	32,113	6,248

SOURCE: Data are from projections described in the text.

TABLE D-6 Projected Ph.D. Workforce and Ph.D.s Outside Science, Assuming Low Trend in Graduates and No Immigration, 1995-2005

	Biomedical Ph.D.s				Behavioral Ph.D.s			
	Male		Female		Male		Female	
Year	Workforce	Outside Science	Workforce	Outside Science	Workforce	Outside Science	Workforce	Outside Science
1995	65,615	6,500	25,825	3,350	31,315	6,477	21,862	3,900
1996	67,318	5,915	27,541	3,346	31,128	6,279	22,534	4,187
1997	68,741	5,505	28,960	3,358	30,909	6,115	23,143	4,444
1998	70,025	5,243	30,340	3,413	30,664	5,962	23,746	4,679
1999	71,176	5,093	31,679	3,498	30,371	5,813	24,339	4,890
2000	72,190	5,027	32,964	3,604	30,011	5,668	24,913	5,076
2001	73,097	5,014	34,206	3,719	29,604	5,529	25,458	5,234
2002	73,907	5,035	35,412	3,841	29,148	5,392	25,984	5,366
2003	74,622	5,078	36,566	3,965	28,624	5,257	26,479	5,482
2004	75,235	5,136	37,667	4,090	28,000	5,104	26,935	5,582
2005	75,743	5,198	38,724	4,216	27,303	4,944	27,338	5,664

SOURCE: Data are from projections described in the text.

cially regarding transition rates, will be the same as in the preceding projections.

Under these conditions, the numbers of graduates that would keep workforce sizes constant would be smaller than the current numbers. This is illustrated in Table D-7, which shows required numbers (without subtracting those who would leave the U.S. after graduation). The negative numbers that appear in one col-

TABLE D-7 Graduates Needed to Produce a Constant Workforce or a Workforce with Fixed Growth, by Field and Gender, 1996-2005

	Biomedical Ph.D.s				Behavioral Ph.D.s			
	Male		Female		Male		Female	
Year	Constant Workforce	Fixed Growth	Constant Workforce	Fixed Growth	Constant Workforce	Fixed Growth	Constant Workforce	Constant Growth
1995[a]	2,955		2,125		1,013		1,388	
1996	684	1,285	–38	201	1,077	1,388	511	716
1997	761	1,373	–43	198	994	1,296	480	691
1998	902	1,525	–5	239	982	1,290	462	678
1999	1,040	1,673	39	285	1,002	1,315	449	667
2000	1,185	1,828	97	346	1,041	1,361	450	671
2001	1,301	1,952	146	397	1,062	1,388	468	692
2002	1,406	2,065	186	439	1,083	1,414	472	701
2003	1,511	2,178	240	496	1,127	1,462	486	719
2004	1,623	2,299	295	556	1,209	1,550	512	748
2005	1,745	2,429	338	602	1,263	1,612	544	787

NOTE: The fixed-growth simulation uses growth rates for the U.S. labor force as a whole: 0.8 percent annually for males, 1.3 percent for females.

[a]Actual, for comparison.

SOURCE: Data are from projections described in the text.

umn suggest that in those years, even with no graduates, the workforce would still expand. (The fixed-growth option shown in the table will be explained below.)

These projections show that if the workforce is not to expand, the number of graduates in biomedical research, in particular, must fall precipitously from 5,100 in 1995 to 650 in 1996. Even by 2005 the required graduates for a constant workforce would still be fewer than half the number of 1995 graduates. In behavioral research the decline in graduates, if a constant workforce were maintained, would be less extreme but still marked. Graduates would have to fall from 2,400 in 1995 to 1,600 in 1996 and increase only slightly by 2005. Table D-7 shows the required number of male graduates rising slightly above their 1995 level, but this increase would be more than offset by the decrease in female graduates.

The numbers of graduates that would produce a constant workforce are well below those assumed in the previous projections (see Figures D-16 and D-17). Even the low projection predicts a larger number of graduates, except for behavioral scientists at the very end of the projection period. To keep the workforce constant, therefore, would require a sharp discontinuity with previous trends, which are based on earlier surveys and shown in the figures.

In these constant-workforce simulations, each of the four groups is projected separately. The ratio of males to females in the workforce, therefore, is constrained not to change. The workforce in a field could of course still be held constant if women replaced departing men, or vice versa. One might then speak simply of 1,600 spaces to fill in the behavioral research workforce in 2000, whether by men or women. The gender of the individuals who fill these spaces would not affect the size of the workforce in that year but could affect its size in later years, since men and women enter the workforce at different ages and have different transition rates.

If women replaced men, would more or fewer graduates be required to maintain a constant workforce? Any difference would appear to be minor at best because various factors tend to cancel each other out. Mainly because of later retirement and also because of lower mortality, female Ph.D.s spend on average more time in the scientific workforce: 29 years for females versus 28 years for males in biomedical research, for instance.

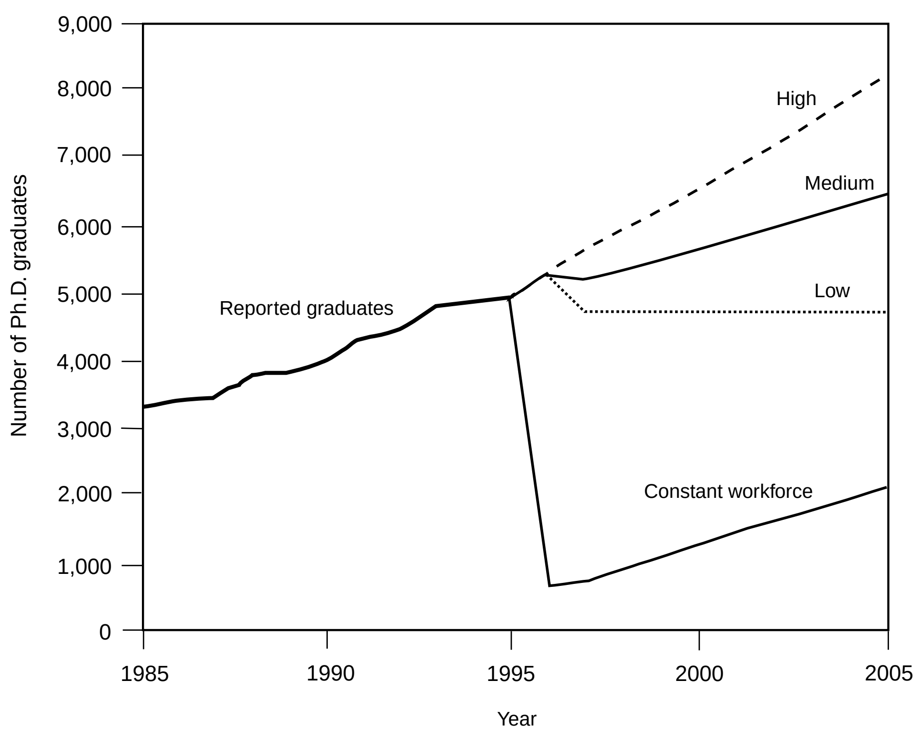

FIGURE D-16 Reported graduates and alternative projections: biomedical scientists, 1985-2005. SOURCE: Data are from the Survey of Earned Doctorates and projections described in the text.

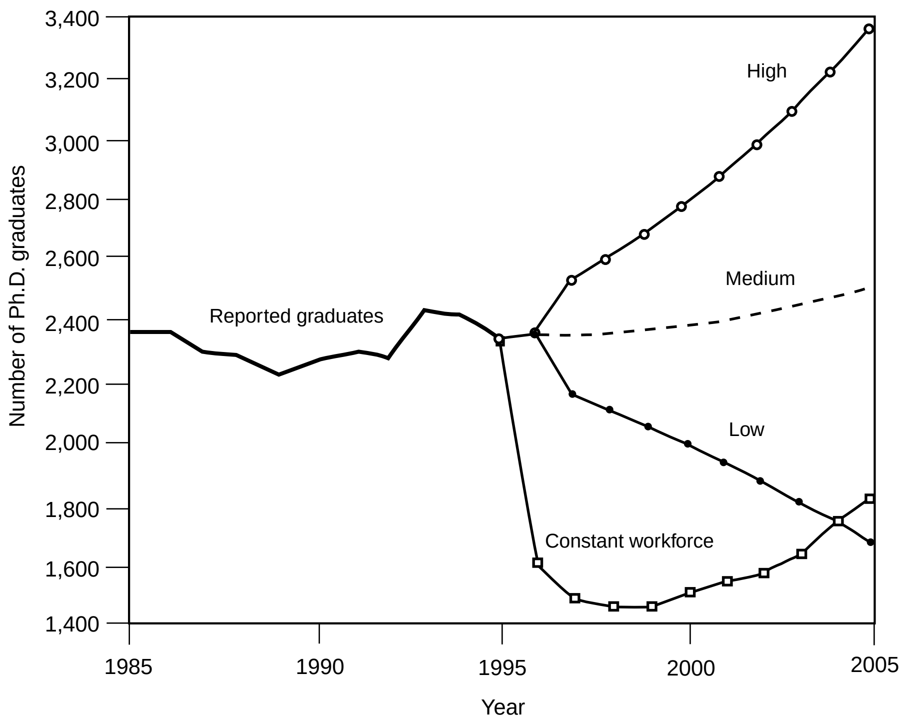

FIGURE D-17 Reported graduates and alternative projections: behavioral scientists, 1985-2005. SOURCE: Data are from the Survey of Earned Doctorates and projections described in the text.

(These estimates are based on the age distribution of graduates in 1995 and on constant transition rates as defined earlier and take into account possible emigration right after graduation.) If actual employment is considered, the advantage shifts to males (who are employed almost one year longer) in biomedical research. Furthermore, women work part-time more often (a factor not in the projections), which reduces the advantage even more. Overall, replacing men with women makes little difference in the projection period and, probably, even in the longer term.

The number of graduates required to maintain a constant workforce of biomedical scientists would rise if Ph.D. immigration were eliminated. Even under this unlikely assumption, however, the number would still be less than current graduation levels. Allowing immigration to rise, on the other hand, would require a further reduction in U.S. graduates. The effects of altering migration assumptions in either direction, however, are fairly small. Changing immigration assumptions for behavioral scientists makes even less difference because immigrants are fewer.

If the overall size of the workforce were to increase, the number of required graduates would naturally be higher than just estimated—how much higher would depend on the growth rates. Fixing the rates at 0.8 percent annual growth for men and 1.3 percent for women—the projected growth rates for the U.S. labor force as a whole[12]—would still imply reductions in graduates (see Table D-7).

For biomedical scientists, the required number of graduates would have to decline substantially—to 1,500 initially, fewer than a third of 1995 graduates. These numbers would double in a decade, but they would stay well below 1995 levels. For behavioral scientists, the required number of graduates would stay close to 1995 levels. A midperiod dip of up to 20 percent would be offset by a later recovery back to the 1995 level.

Graduate Projections and Enrollment

These projections of Ph.D. graduates have been made without reference to enrollments because, as

[12] Fullerton, Howard N. “The Labor Force in 2006: Slowing Down and Changing Composition.” *Monthly Labor Review* 120, no. 11 (1997): 23-38.

noted earlier, enrollment in a given year does not predict the number that will eventually graduate. Enrollment ultimately does set limits on graduates, however, and looking at these limits may suggest whether and how enrollments may need to change.

As also noted earlier, the number of enrollees in a given year has been generally between 1.4 and 2.8 times the number of graduates six years later in these two fields for a decade. Whether the ratio for any given cohort will be closer to the high or the low end may not be predictable; however these figures may establish rough upper and lower limits on the number of future graduates.

These limits are illustrated for biomedical researchers in Figure D-18. The actual number of graduates year by year consistently remained within the limits but moved continuously toward the upper limit through the 1980s and early 1990s. The medium projection maintains this upward movement but keeps the number within the limits set by enrollment. (The upper limit of enrollment will be approached fairly closely toward the end of the projection.) Nevertheless, if graduate enrollments in biomedical research remain constant in 1998 and 1999, the medium projection should be achievable in 2004 and 2005 without breaching the upper limit.

The fixed-growth simulation, on the other hand, would drop the number of graduates below the lower limit set by enrollment. This means that if the biomedical research workforce grew only at the rate of the U.S. labor force, considerably smaller proportions of those enrolled in recent years would have to graduate than at any point in the preceding decade.

A similar representation of the behavioral research workforce considers fewer years, since it excludes earlier enrollment data that do not distinguish behavioral researchers from clinical psychologists (see Figure D-19). Both the medium projection of graduates and the fixed-growth projection provide figures that lie comfortably within the limits set by recent enrollments. Only a sharp one- or two-year decline in enrollment of at least 20 percent (unprecedented in recent years) would hamper the attainment of the projected number of graduates and even then only for the last two years of the projection.

In behavioral research, considerable leeway exists for the trend in graduates to change either upward or

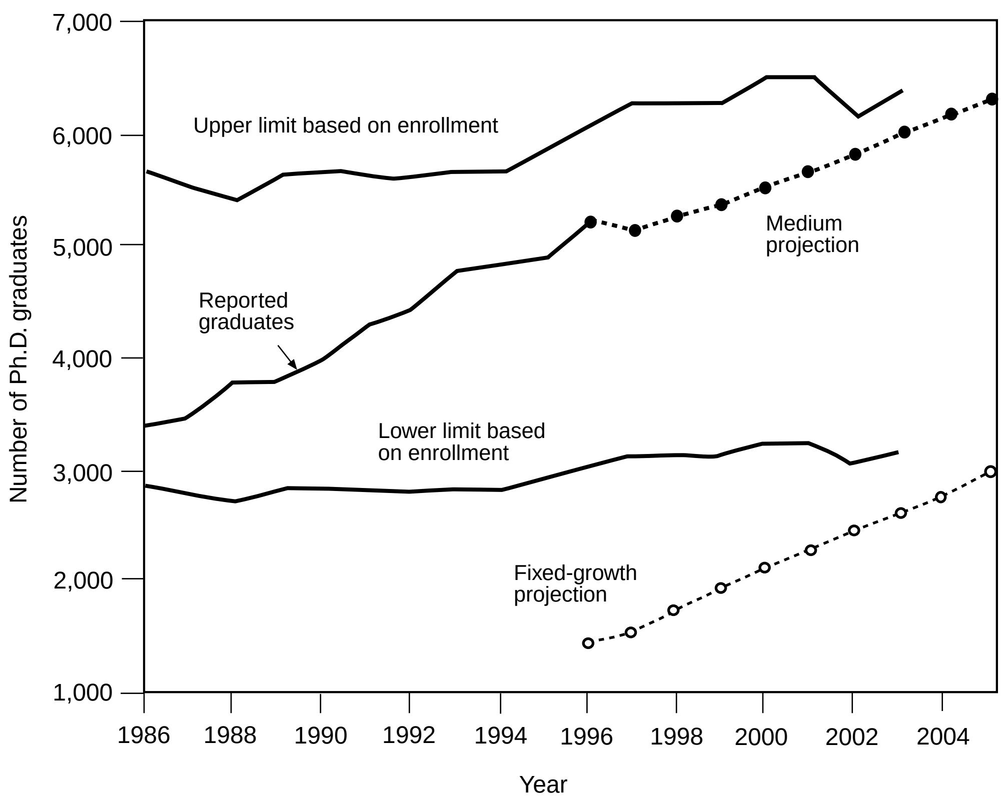

FIGURE D-18 Reported and projected graduates and limits set by enrollment lagged six years: biomedical scientists, 1986-2005. SOURCE: Data are from the Survey of Earned Doctorates and estimates and projections described in the text.

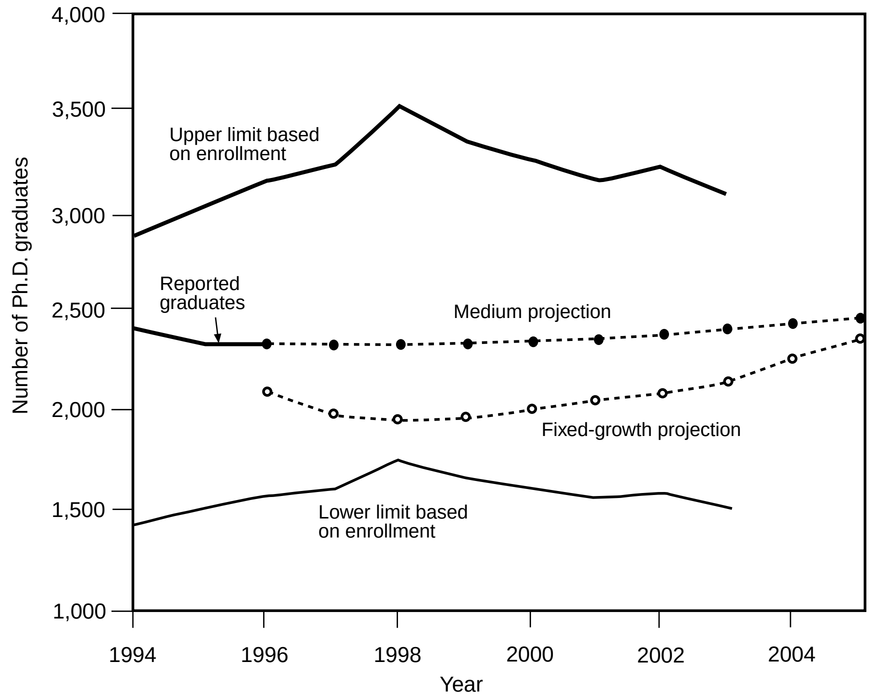

FIGURE D-19 Reported and projected graduates and limits set by enrollment lagged six years: behavioral scientists, 1994-2005. SOURCE: Data are from the Survey of Earned Doctorates and estimates and projections described in the text.

downward without altering enrollment. Even 3 percent annual growth, which is three times the projected rate (similar to the growth in the biomedical research workforce), could be accommodated by constant enrollments and would require only relatively moderate and historically achievable changes in the ratio of graduates to preceding enrollments.

IMPLICATIONS AND REFINEMENTS

If recent experience is a proper guide, the Ph.D. workforce in biomedical and behavioral research will continue to grow. In each field the current number of Ph.D. graduates substantially exceeds the number needed for a workforce of constant size. In addition, in biomedical research the number of graduates is clearly rising. Given current enrollment rates in graduate programs in the basic biomedical fields, the numbers of Ph.D. graduates are likely to at least continue at current levels for the next few years, or even increase. These conclusions are drawn from several projections. These are not meant as forecasts; the implications of a set of predefined assumptions have simply been worked out. Assumptions were chosen that reflect the recent behavior of the workforce, but no claim can be made that this behavior will in fact be replicated in the future. Dramatic changes in movement into and out of science or substantial variation in entering graduates or immigrants could presumably change the picture. The recent historical record suggests considerable biennial variation in the size of the workforce, variation not factored into the projections and deserving closer study.

Labor demand and education subsidy factors have not been incorporated into the model used here, though they could be important if substantial future discontinuities with recent experience occur. The employment outlook in these fields, the funding available for graduate education and research, and the status of immigrants and foreign students are all matters on which no judgment has been passed. In principle, such factors could be incorporated as predictors of entry and exit into the workforce, thus refining the projections.

Demand factors will constrain growth in these fields, if the workforce projections of the Bureau of Labor Statistics[13] are accurate. The bureau's projections are primarily driven by demand, proceeding from aggregate economic growth to commodity requirements to

[13] U.S. Bureau of Labor Statistics. *Handbook of Methods*. Washington, D.C.: U.S. Department of Labor, 1997.

the implied growth in specific industries. Projected industry trends are then converted into trends in occupations using a matrix relating over 250 industries to 500 occupational categories.[14] As noted above, for the categories corresponding most closely to those used here, bureau projections show growth rates only two-thirds as high as the medium projections here for biomedical scientists and three-fourths as high for behavioral scientists. The demand for researchers in these fields, therefore, is projected by the bureau to fall short of the supply projected here. If that turns out to be the case, the numbers of students entering these fields would presumably decline. Whether this decline would be timely and whether it would be too much or too little to avoid increased unemployment or underemployment is impossible to predict.

The transition rates and other input data and assumptions used here have substantial limitations and could in principle be improved in various ways. In particular, future forecasts of the research workforce would benefit from better information on employment outside science, immigration, foreign students, and the clinical research workforce. Historical trends in employment outside science cannot be thoroughly assessed due to data limitations, but some members of the Ph.D. workforce appear to move into and out of science jobs. The accuracy of the model could be improved through better information about such job shifts and the specific employment fields involved, as well as through further analysis of these trends. Data on immigrant Ph.D.s, who are roughly equivalent to a tenth of the workforce in biomedical research, should also be examined more closely. Their numbers and rates of increase have been estimated from quite limited data, and the factors that will affect their future numbers are undetermined. Foreign Ph.D. students have increased in the 1990s to the point where they make up 37 percent of biomedical research graduates and 17 percent of behavioral research graduates. A further increase in the number of foreign students could affect the workforce if it is not counterbalanced by a change in stay rates. If stay rates for foreign students decline, additional numbers of U.S. citizens and permanent residents could enter the workforce without increasing its overall size. Finally, our understanding of the health research workforce could be improved by incorporating clinical researchers into this analysis. Existing data on M.D.s and other doctoral-level health care professionals in research is insufficient to project the size of the clinical research workforce, but such an assessment might be undertaken with additional data collection and analysis.

Three other transitions have been ignored, partly for reasons of data and partly because they appear inconsequential; however, this cannot be established with certainty. The first of these is emigration of Ph.D.s; only the emigration of foreign graduates who leave shortly after graduation has received attention. The second is return migration of these emigrant Ph.D.s. (There are a few return migrants among foreign graduates, as Finn's[15] data show, and there may be more among U.S.-born Ph.D.s.) The third is the return to the workforce of those who have retired. Introducing such transitions into the model could lead to a number of complications. It may be desirable, for instance, to determine a separate mortality schedule for the retired. The importance of considering such transitions in more detail depends on the precision required in projections and their potential uses. Nevertheless, such other transitions, and most of the specifications used here, would be better understood and modeled with more complete data.

TECHNICAL NOTE: THE PROJECTION MODEL

The projection model is illustrated in Figure D-1. It is a multistate life-table model, as recommended by a previous committee of the National Research Council,[16] but various specifics differ.

For any group specified by field and gender, the number employed in science at age j in year i is represented by E_{ji}, and similarly the number unemployed is U_{ji}, the number not in the labor force is V_{ji}, and the number outside science is O_{ji}. The potential workforce of the specified gender in a given field then is

$$W_{ji} = E_{ji} + U_{ji} + V_{ji}$$

with j running from age 25 to age 76.

Let the probability of moving from employment to unemployment from one year to the next at a given

[14] Ibid.

[15] Finn, Michael G. "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 1995." Oak Ridge, Tenn.: Oak Ridge Institute for Science and Education, 1997.

[16] National Research Council. *The Use of Multi-State Life Tables in Estimating Places for Biomedical and Behavioral Scientists: A Technical Paper*. Washington, D.C.: National Academy Press, 1997.

starting age j be represented by eu_j, the probability of moving from employment out of the labor force by ev_j, the probability of moving from employment in science to outside science by eo_j, and the other probabilities of movement between these groups be similarly represented. Add the notation er_j to represent transition from being employed to being retired, and ed_j from being employed to being dead (and similarly for the other employment-status groups, but note that, given no better data, the mortality schedule is assumed to be identical across groups). These probabilities are all assumed to be constant over time.

The probabilities are also assumed to be conditional one on the next. For example, the probability of moving from employment to retirement is conditional on the individual's not dying in that period. Conditional probabilities are convenient to use because this simplifies the assumptions one has to make in estimating them from the data.

From these definitions, one can represent those at a given age j+1 who are employed in science in a given year i+1, leaving out new entrants, as

$$\begin{aligned} E_{j+1,i+1} = {} & E_{ji}\,(1\text{-}ed_j)\,(1\text{-}er_j)\,(1\text{-}ev_j)\,(1\text{-}eu_j)\,(1\text{-}eo_j) + \\ & U_{ji}\,(1\text{-}ud_j)\,(1\text{-}ur_j)\,(1\text{-}uv_j)\,(1\text{-}uo_j)ue_j + \\ & V_{ji}\,(1\text{-}vd_j)\,(1\text{-}vr_j)\,(1\text{-}vu_j)\,(1\text{-}vo_j)\,ve_j + \\ & O_{ji}\,(1\text{-}od_j)\,(1\text{-}or_j)\,(1\text{-}ov_j)\,(1\text{-}ou_j)\,oe_j. \end{aligned}$$

Similar expressions apply to the other employment status groups.

Graduates (G_{ji}) and immigrants (H_{ji}) entering the workforce at age j in year i are projected as discussed in the text. For graduates, the specific equations on year since 1900 (y = i – 1900) for the high projection are as follows:

Male biomedical scientists
$12{,}438 - 307\,y + 2.18\,y^2$, $R^2 = 0.98$
Female biomedical scientists
$20{,}178 - 515\,y + 3.42\,y^2$, $R^2 = 0.99$
Male behavioral scientists
$26{,}930 - 557\,y + 2.99\,y^2$, $R^2 = 0.84$
Female behavioral scientists
$10{,}071 - 221\,y + 1.37\,y^2$, $R^2 = 0.87$

For behavioral scientists, the equations for the low projection are

Male behavioral scientists
$4{,}313 - 29\,y - 0.07\,y^2$, $R^2 = 0.86$
Female behavioral scientists
$-10{,}718 + 256\,y + 1.35\,y^2$, $R^2 = 0.93$

For biomedical scientists the low projection is based on a constant number of graduates. For all groups the medium projection is the average of the high and the low projections.

Graduates who stay in the country and immigrants are assumed to distribute themselves across the four employment status groups (including outside science) in proportion to those already in these groups at age j in year i. In case there are fewer than 50 individuals already at a given age, proportions are taken over three or five contiguous single-year age groups and, if this criterion is still not met, over the entire age distribution. Entering graduates and immigrants are assumed not to retire or die for at least a year. Graduates are limited to the age range 25-50 and immigrants to the age range 25-70.

To estimate the number of entering graduates necessary to keep the total workforce constant over time, a projection is run one year at a time assuming no graduates. The gap between the projected workforce and the starting workforce is then estimated, and the graduates necessary to fill this gap are calculated, which allows this number to be greater than the actual gap because some graduates leave the country and others take jobs outside science.

These graduates can be distributed by age to parallel their distribution in the year before the projection starts. Designate this year as year 0 and let pw_j stand for the proportion in the workforce (as opposed to outside science) at age j. Then

$$G_{ji} = \frac{G_{j0}\;3_j(kW_{j0} - W_{ji})}{3_j G_{j0} pw_j},$$

where k = 1. To allow the workforce to grow or decline by some fixed rate, k can be set equal to one plus that rate.

The projections require Ph.D. immigrants by year, which are estimated by reverse survival. The first step is to divide the two-year cohorts in the survey arbitrarily in half to give single-year cohorts and facilitate calculations. The number of migrants resident in the U.S. is assumed to be equal to the number entering the country, after adjustment for retirement and death over the period since entry. (Other transitions, such as return migration, are not considered.) For age group j, let R_{ji} represent the immigrants remaining in the country in year i. Also define s_j as the survival rate for age group j, the proportion that neither die nor retire in one year:

$$s_j = (1 - td_j)(1 - tr_j),$$

where td_j is the weighted proportion dying among those employed, unemployed, not in the labor force, and outside science (= ed_j, the proportions for all these groups being equal), and tr_j is the weighted proportion retiring among those in these groups who do not die. (These factors are specific by field and gender, but subscripts are not shown for that.) Then the immigrants entering in 1985-86 should be

$$R_{j,1985.5} = R_{j+8,1993} / s_{j-1} / s_{j-2} / s_{j-3} / s_{j-4} / s_{j-5} / s_{j-6} / s_{j-7} / /s_{j-8}$$

The results of these calculations were converted to annual numbers, dividing each two-year period in two. Figures for the last period (1987-90) were divided by 3.5, on the assumption that the period is truncated because migration had to take place before the 1990 census. After averaging across periods, the distribution by age was smoothed using five-year moving averages.